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ECE606: Solid State Devices
Lecture 1: Introduction

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Outline

1) **Course information**
2) Current flow in semiconductors
3) Types of material systems
4) Classification of crystals

Reference: Vol. 6, Ch. 1 (pages 1-10)

Course Information

Books

- Advanced Semiconductor Fundamentals (QM, SM, Transport)
- Semiconductor Device Fundamentals (Diode, Bipolar, MOSFET)

Website

http://cobweb.ecn.purdue.edu/~ee606/

Office hours 8:20-9:15 MWF @ EE 320

HW/Exams

HW (9 HW, 4 will be graded; solutions will be provided)

3 exams (~5 weeks apart)

Outline of the Course

Application specific device operation ← **Physical Principle of device operation** ← **Foundation in Physics**

Device-specific system design ↙

EE606

- TFT for Displays
- CMOS-based Circuits for μP
- LASERS for Disk Drives
- MEMS for Read heads

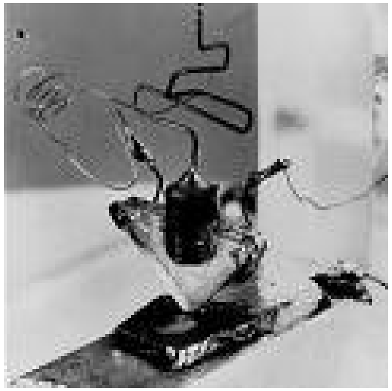
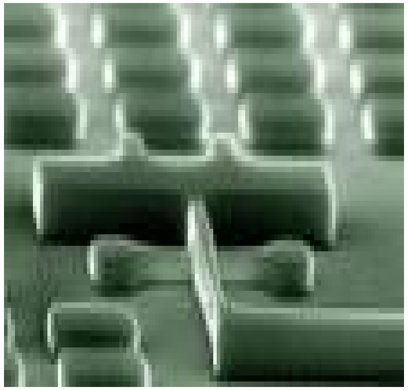
- Resistors (5 wk)
- Diodes (3 wk)
- Bipolar (3 wk)
- MOSFETs (3 wks)

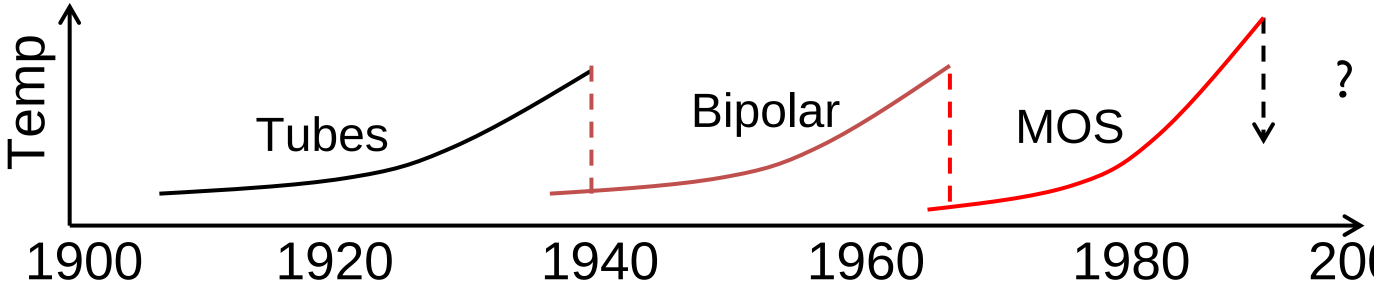
Quantum Mechanics
+
Statistical Mechanics
↓
Transport Equations

Relation to Other MN-Area Courses

Device-specific system design	EE 695F: RF Design	EE 695E: Opto-system	BME 695A: Bio-system Design
Application specific device operation	EE 654: Advanced Semi Dev.	EE 612: VLSI Devices	EE 520: Bio-Systems
Physical Principle of device Operation	EE 606: Basic Semi Dev.	EE 604 EM, Magnetics	
Foundation	EE 656: Semi-Transport	EE 659: Quantum Transport	PHYS 570B : Bio-physics
	Finite Element, Molecular Dynamics, Monte Carlo	Characterization	

Grand Challenges in Electronics

Vacuum Tubes	Bipolar	MOSFET	Now ??
			Spintronics Bio Sensors Displays ….
1906-1950s	1947-1980s	1960-until now	



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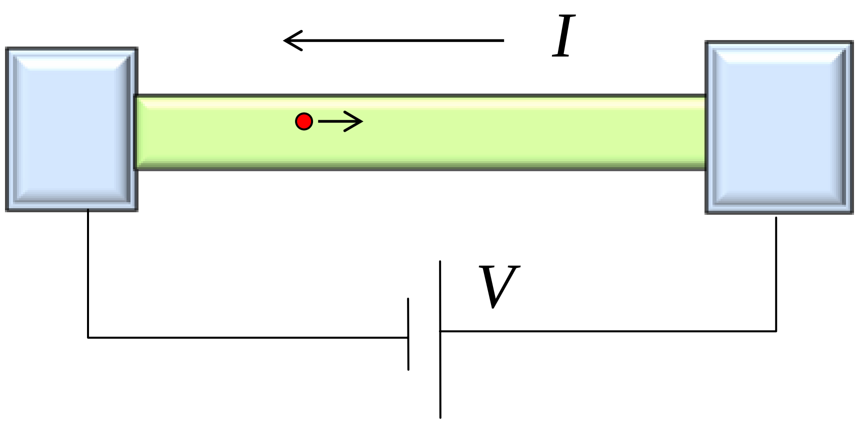
Current Flow Through Semiconductors (5 weeks)



$$I = G \times V$$
$$= q \times n \times v \times A$$

Carrier Density → n; velocity → v

Depends on chemical composition, crystal structure, temperature, doping, etc.

Quantum Mechanics + Equilibrium Statistical Mechanics
$\Rightarrow$ Encapsulated into concepts of effective masses and occupation factors (Ch. 1-4)

Transport with scattering, non-equilibrium Statistical Mechanics
$\Rightarrow$ Encapsulated into drift-diffusion equation with recombination-generation (Ch. 5 & 6)

Computing Carrier-Density and Velocity

Atomic composition

- *number of electrons per atom*

Arrangement of atoms

- *not all electrons are available for conduction*

For Periodic Arrays

- *simplification for computation*

$\Rightarrow$ Concept of Unit Cells

$\Rightarrow$ Simple 3-D Unit Cells

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Elemental and Compound Semiconductors

II	III	IV	V	VI
4 Be	5 B	6 C	7 N	8 O
12 Mg	13 **Al**	14 **Si**	15 **P**	16 S
30 **Zn**	31 **Ga**	32 Ge	33 **As**	34 **Se**
48 Cd	49 In	50 Sn	51 Sb	52 Te
80 Hg	81 Tl	82 Pb	83 Bi	84 Po

Elemental (e.g., Si, C)

Compound

IV-IV: Si-Ge, Si-C

III-V: InP, GaAs, $(In_xGa_{1-x})(As_yP_{1-y})$

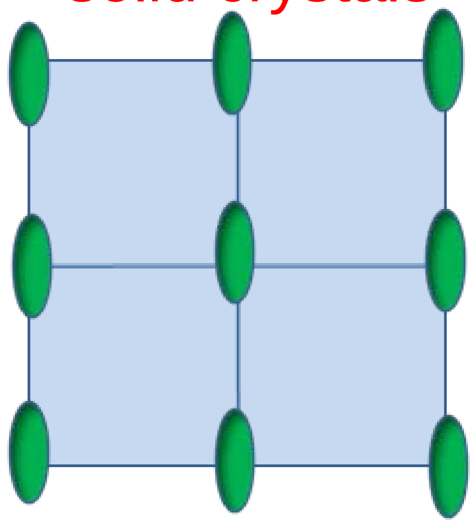
II-VI: CdTe

IV-VI: PbS

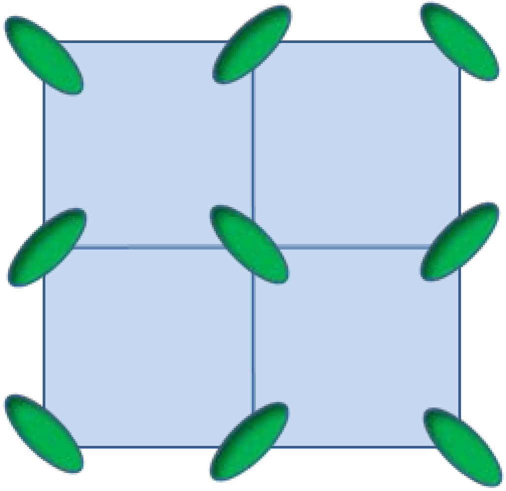
Not all combinations possible:
lattice mismatch, room temp. instability, etc. are concerns

Arrangement of Atoms: orientation vs. position

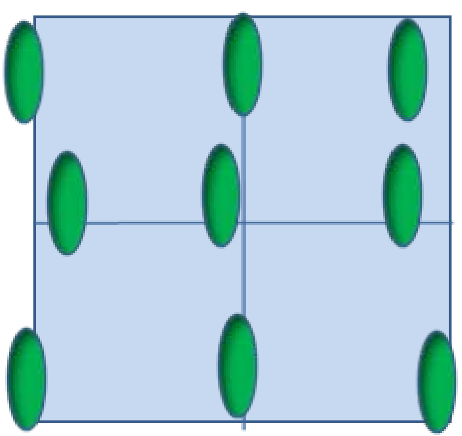
solid crystals



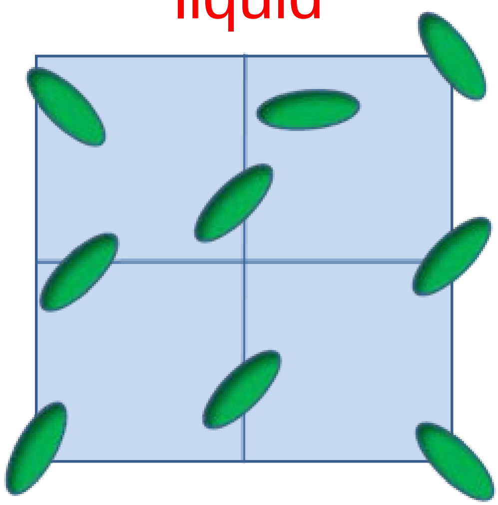
plastic crystals



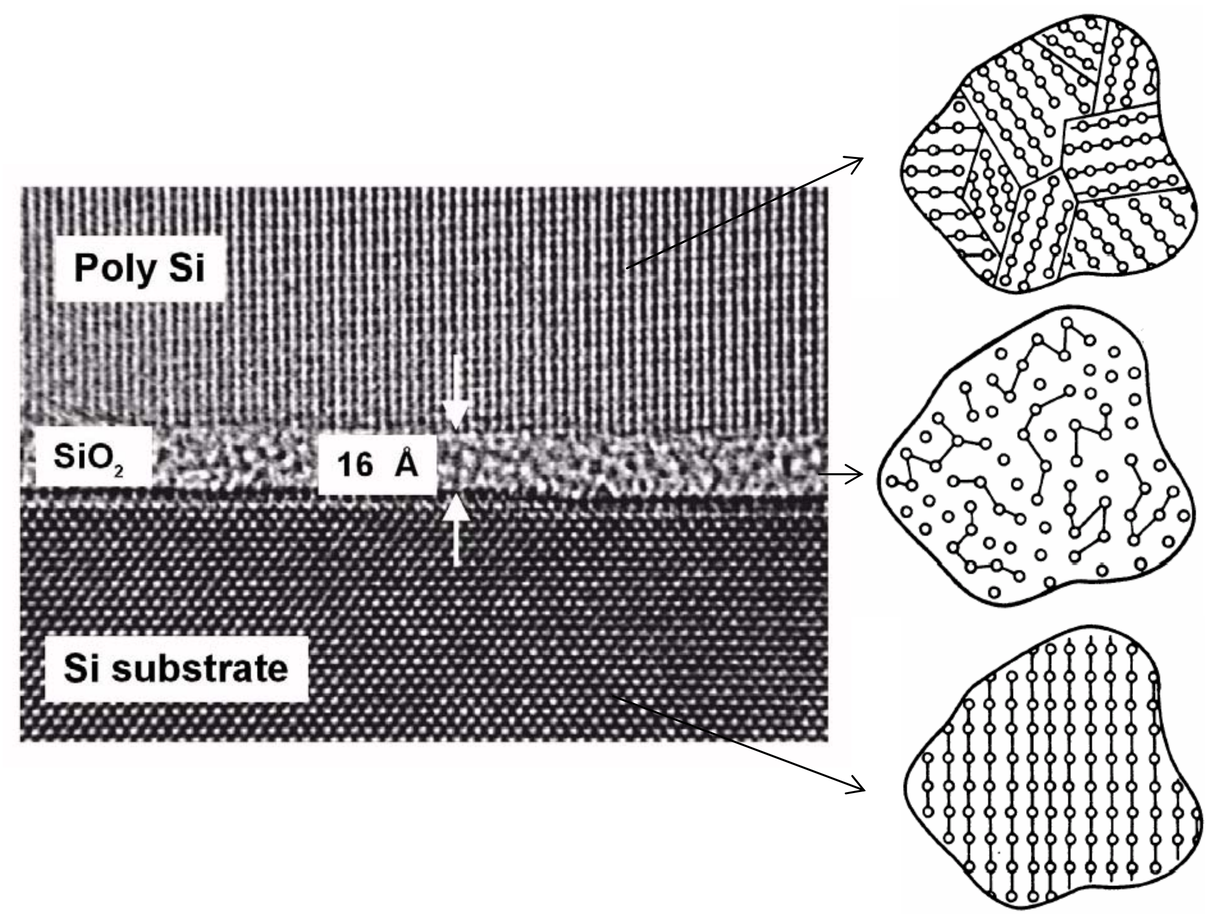
liquid crystals



liquid



Arrangement of Atoms



Poly-crystalline
Thin Film
Transistors

Amorphous
Oxides
Why ?

Crystalline
Definition ?

- Quantitative definition: Correlation spectrum and diffraction pattern
- Modern solid state devices use all forms these forms of materials

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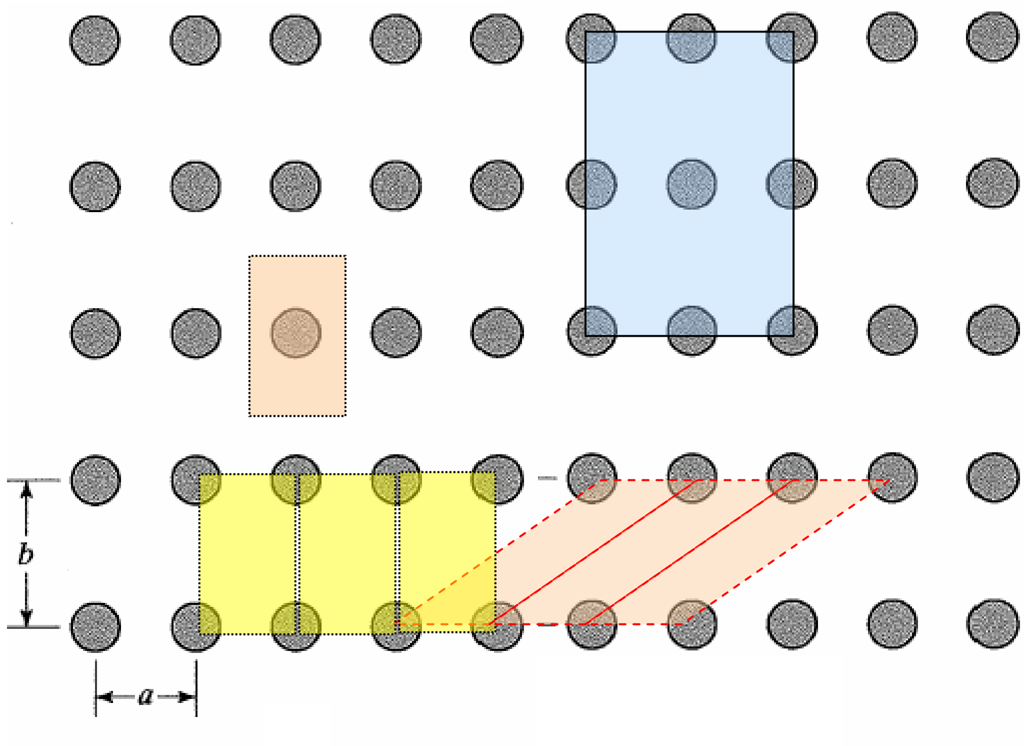
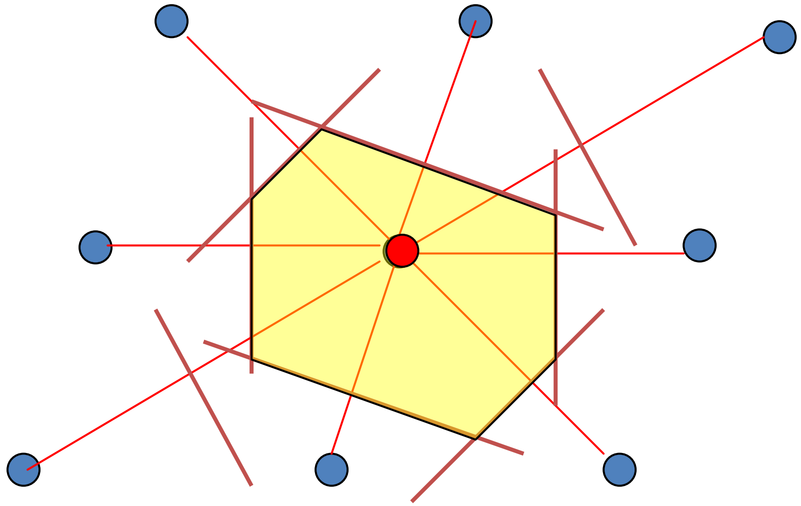
Unit cell of a Periodic Lattice



- Unit cells are *not* unique
- Unit cells can be Primitive or Non-primitive
- Property of one defines the property of the solid

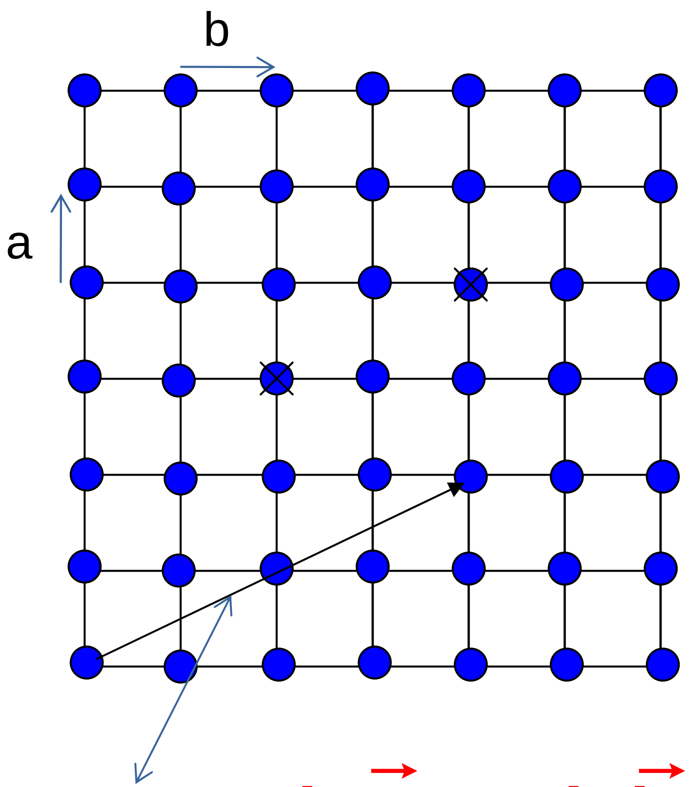
Wigner-Seitz Primitive Cell

- Choose a reference atom
- Connect to all its neighbors by straight lines
- Draw lines (in 2D) or planes (in 3D) normal to and at the midpoints of lines drawn in step 2
- Smallest volume enclosed is the Wigner-Seitz primitive cell

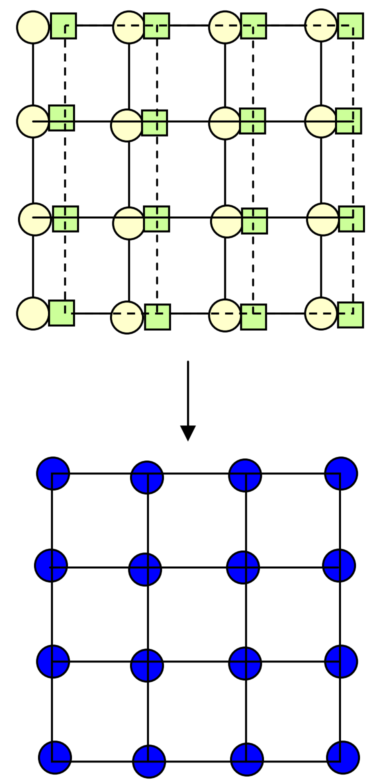


Geometry of Lattice Points

In a Bravais lattice, every point has the same environment as every other point (same number of neighbors, next neighbors, .

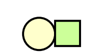


$$\vec{R} = h\vec{a} + k\vec{b}$$

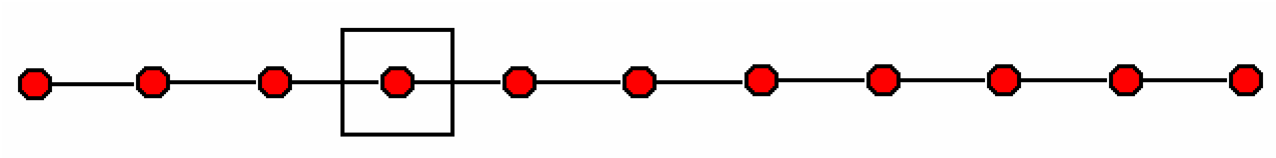


Non-Bravais lattice

Bravais lattice with a basis



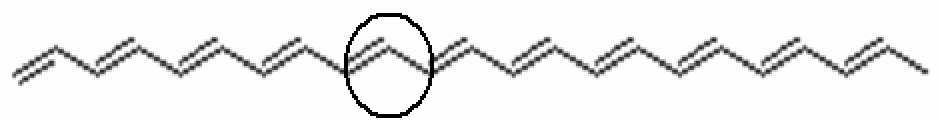
Unit Cells in One-dimensional Crystals



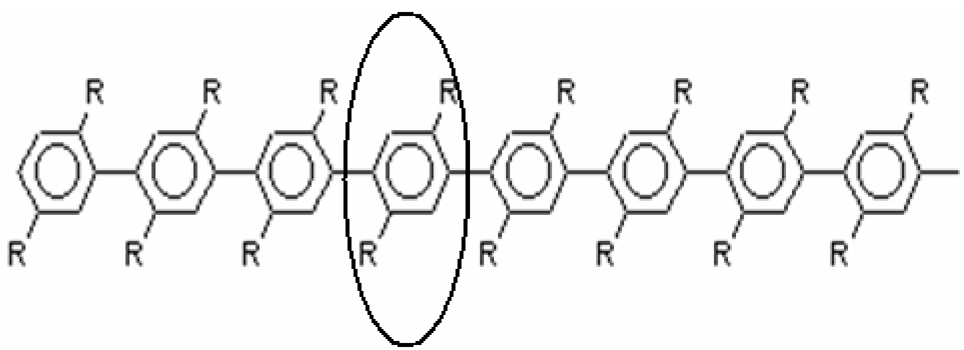
No system truly 1-D, but ….

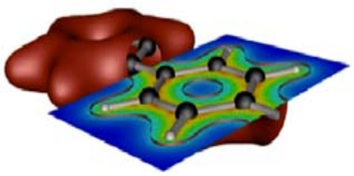
- 1D properties dominate behavior in some material (e.g., polymers)
- Can be solved analytically, many properties have 2D/3D analogs

Polyacetylene

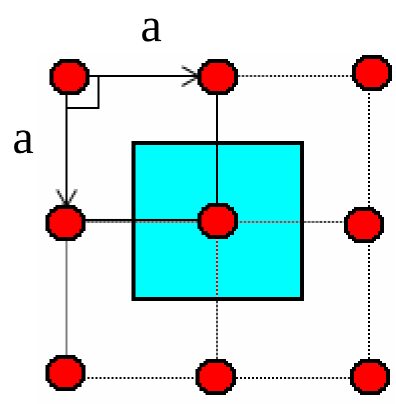


PPP

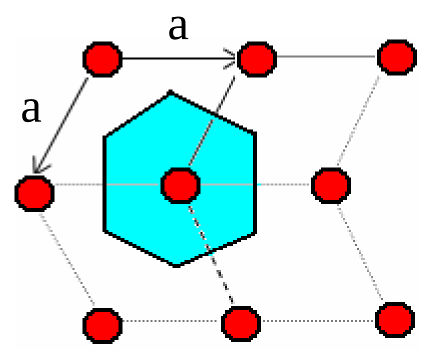




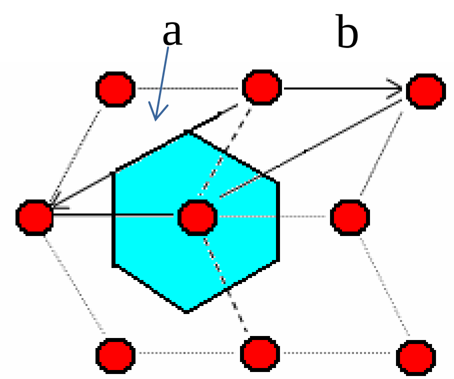
Periodic Lattice in 2D (5-types)



a=b, ϕ=90



a=b, ϕ>90



Gener
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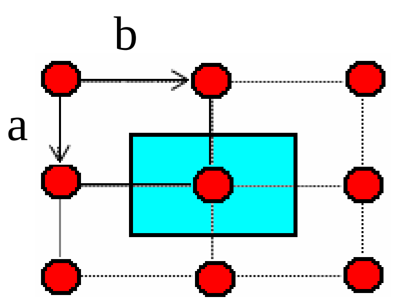
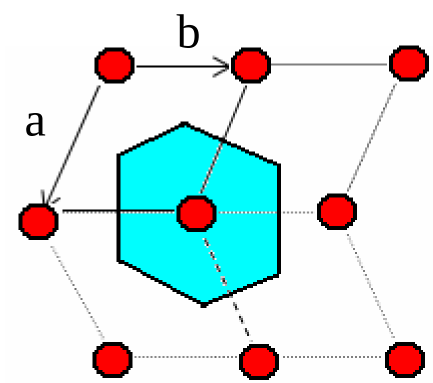


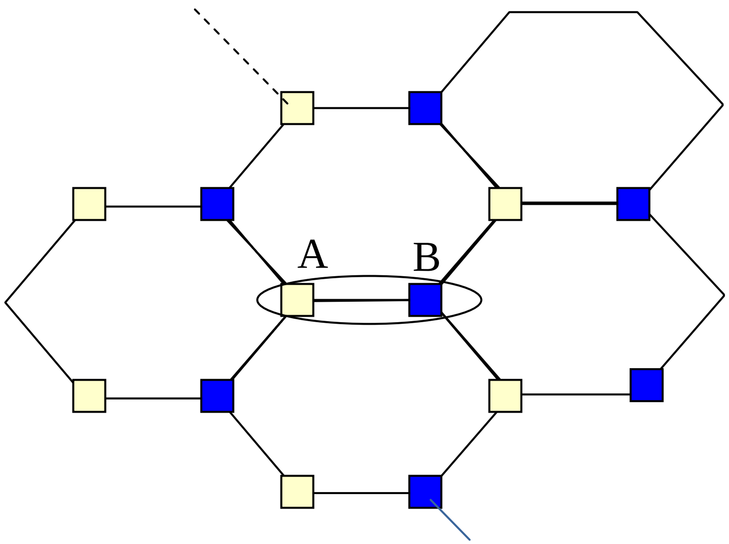
a<b, ϕ=90



a>b, ϕ>90

- Many systems have 2D lattice (e.g., Graphene, Wigner crystals, …)

Not a Bravais Lattice …



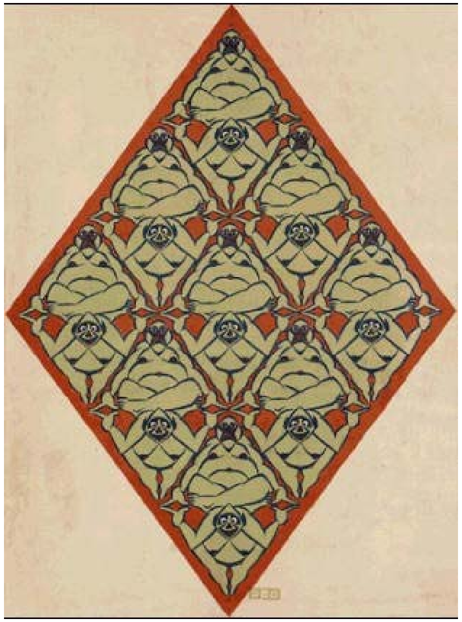
This is a Graphene sheet which has recently been isolated from Graphite by adhesive tape stamping.

Ref. Novoselov, Geim, et al. Nature, 438, 197, 2005.

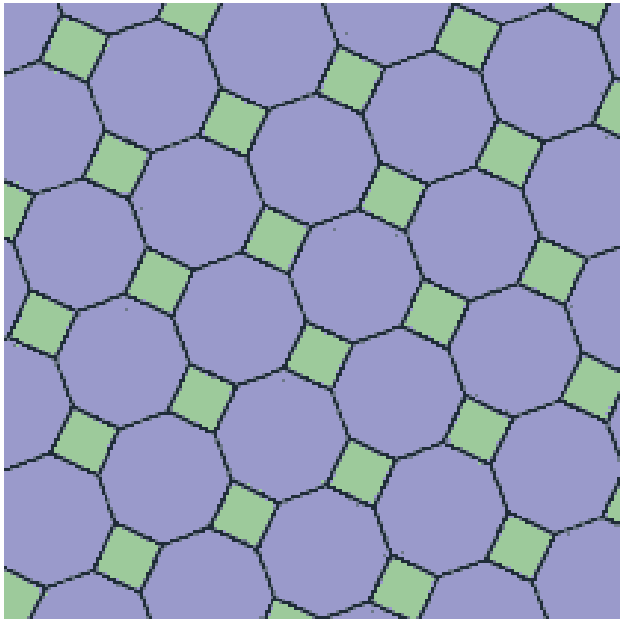
A and B do not have identical environments

Not a Bravais Lattice, but …

Escher Tiling



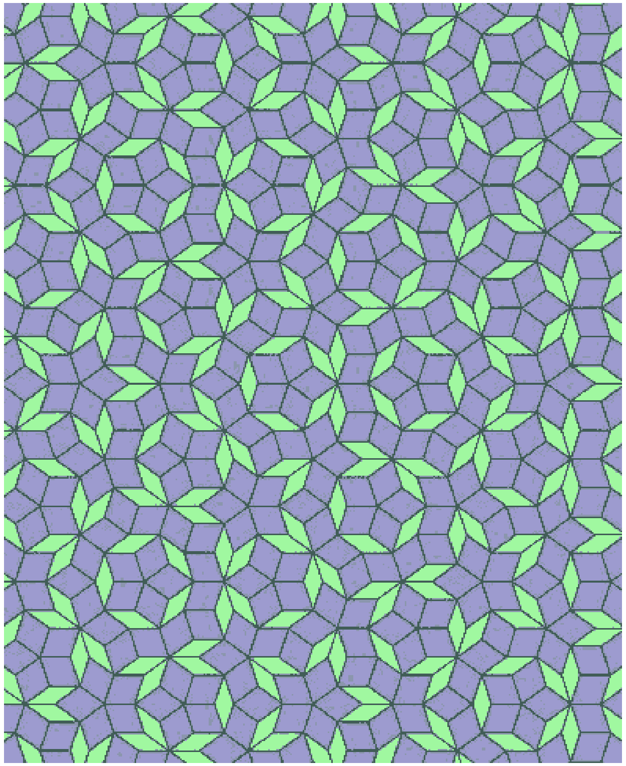
Kepler Tiling



….but these can be converted into Bravais lattice

Not a Bravais Lattice and ...

Penrose Tiles



Ancient Tiles

... these CANNOT be transformed to Bravais lattice
ex. Aluminum-Manganese compounds, non-sticky coats

Bravais lattice in 3D (14-types)

<table>
<tr><th></th><th>Triclinic</th><th>Cubic</th><th>Tetragonal</th><th>Orthorobmic</th><th>Rhombohedral</th><th>Hexagonal</th><th>Monoclinic</th></tr>
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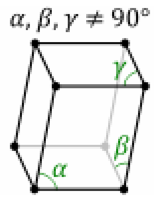
<td>
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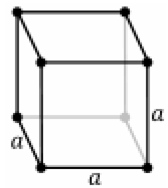
<td>
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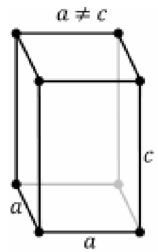
<td>
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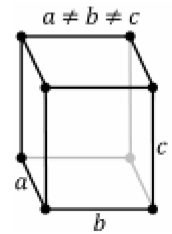
<td>
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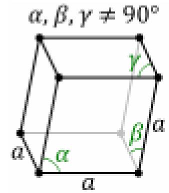
<td>
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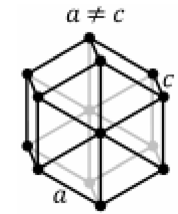
<td>
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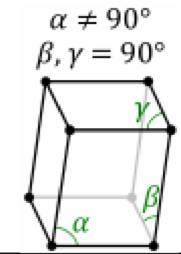
<td>
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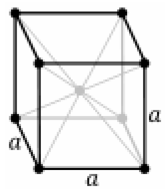
<td>
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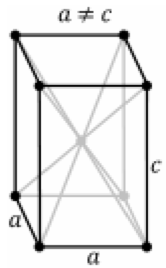
<td>
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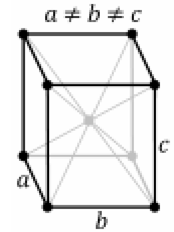
<td>
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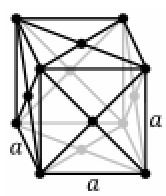
<td>
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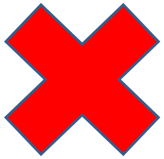
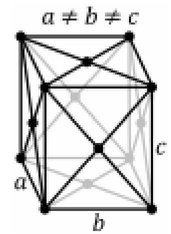
<td></td>
<td>
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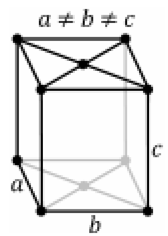
<td>
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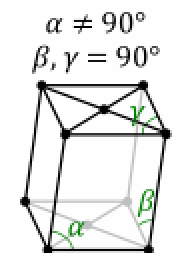
<td>
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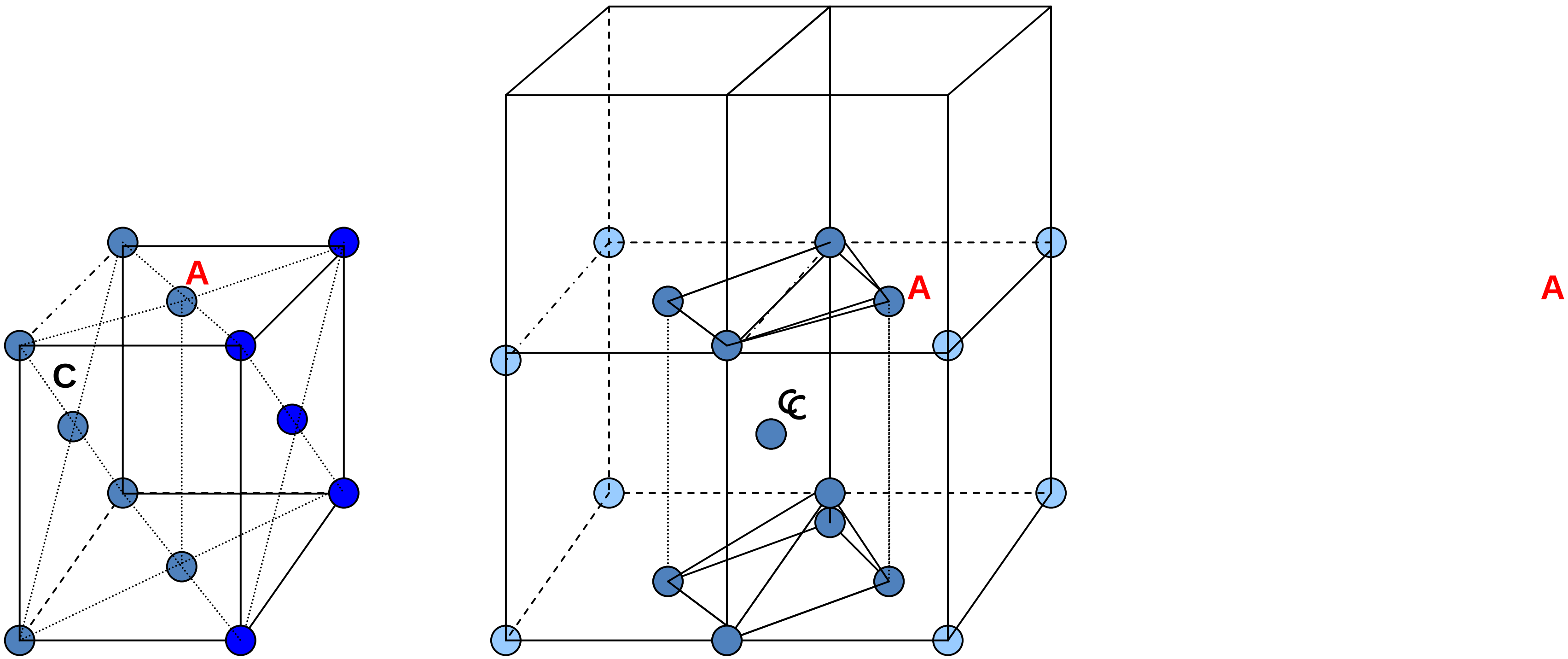
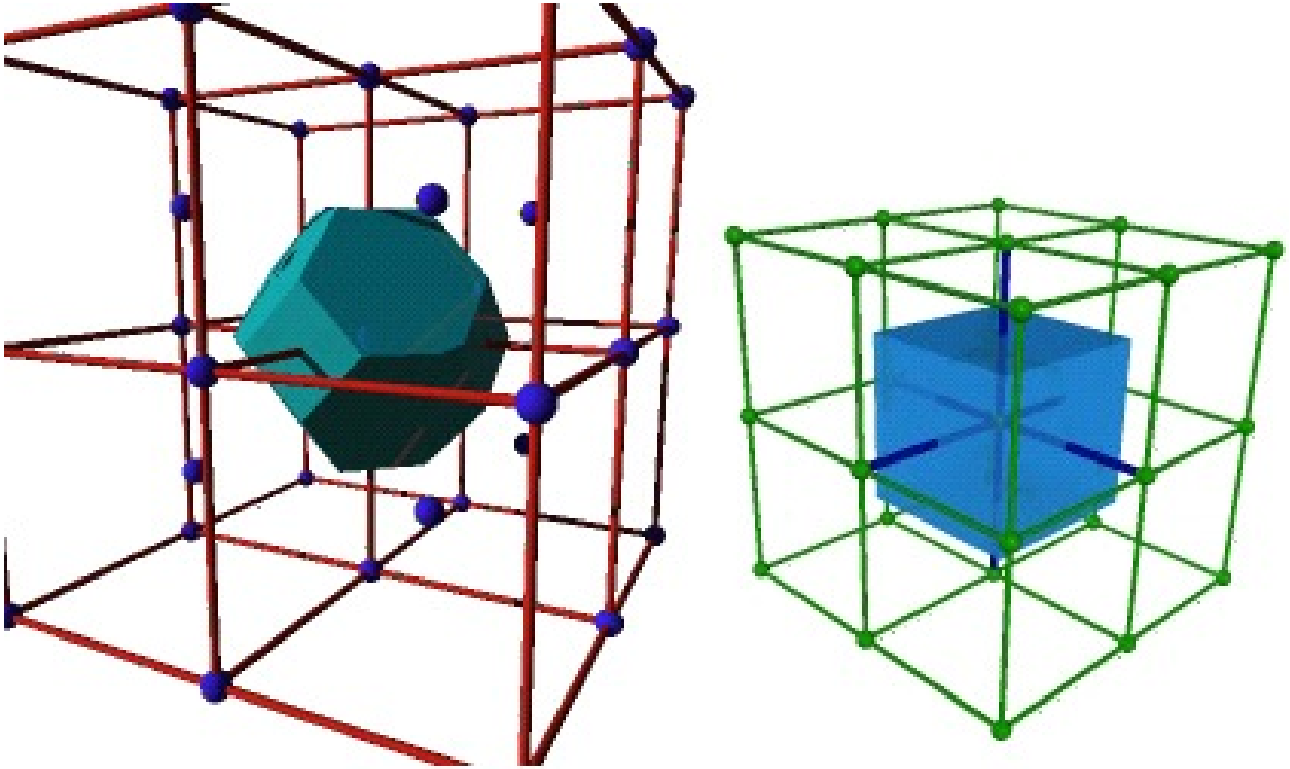
Duplicated Bravais Lattice

Unlucky Frankenheim (1842)!



Tetragonal BC = Tetragonal FC

Wigner-Seitz cells for BCC and Cubic Lattices



Laura Malcolm, 1997

Conclusions

1. Transport in semiconductors depends on carrier density (n) and carrier velocity (v). In order to find these quantities, we need to understand the chemical composition and atomic arrangements.

2. There is a wide variety of semiconductor materials (IV, III-V, II-IV, etc.) with different chemical compositions.

3. Crystalline materials can be built by repeating the basic building blocks. This simplifies the quantum solution of electronic states, which will allow us to compute (n) and (v) for these systems easily.